

Low-Loss, Low-Noise, Crystalline Silicon Dielectric for Superconducting Microstrip and Kinetic Inductance Detector Capacitors

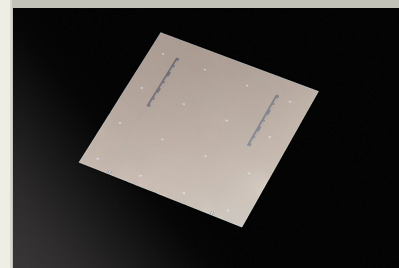
Completed Technology Project (2015 - 2017)



Project Introduction

Development of technology to use crystalline dielectrics in superconducting spectroscopic sensors operating in the infrared/sub-millimeter wavelength range. The technology is expected to help enable Physics of the Cosmos and Cosmic Origins mission needs.

Prospective future PCOS (Inflation Probe) and COR (FIR Surveyor, FIR Interferometer) missions require large arrays of highly sensitive millimeter-wave and submillimeter (mm/submm) detectors, including spectroscopic detectors. A number of JPL-pioneered technology developments in superconducting sensors for these applications require low-loss dielectric thin films. Examples include: 1. superconducting phased-array antennas (such as those used in the BICEP2, Keck Array, BICEP3, and SPIDER suborbital CMB polarization receivers and the Caltech Submillimeter Observatory's MUSIC multiband camera), which rely on superconductor-dielectric-superconductor microstrip transmission line to coherently sum radiation received by arrays of slot dipole antennas and to define spectral bandpasses; 2. superconducting spectrometers (SuperSpec), which use such microstrip to route optical power to detectors and to define spectral channels; 3. and kinetic inductance detectors (KIDs), which use capacitors. In the above, the loss of the dielectric, quantified by the loss tangent, is critical: it determines the optical loss in the microstrip, the resolution of spectral channels, and the two-level-system (TLS) dielectric fluctuation noise of the KID capacitor. Currently, amorphous dielectrics (SiO₂, SiN_x, amorphous hydrogenated silicon (a-Si:H)) are used because they are most convenient for fabrication. They have loss tangent $\sim 10^{-3}$. Crystalline silicon has loss tangent $< 5 \times 10^{-6}$, 200 times lower. Incorporating it into microstrip and capacitors would result in a quantum leap in capability, opening up design space heretofore inaccessible and enabling design innovations. The reliability of crystalline silicon would also improve fabrication uniformity and robustness. Specific impacts on the above technologies would be: a) For phased-array antennas, lower optical loss would allow the detectors to be moved away from the antenna and shielded from absorption of light that has not been spatially or spectrally filtered by the antenna and bandpass filters. Doing so would also simplify detector wiring by obviating long wiring busses from the edge of each chip to each detector. More sophisticated antenna designs, such as multiscale antennas that could cover a decade of spectral bandwidth, could be entertained. b) For superconducting spectrometers, lower loss would improve the spectral resolution limit, $R_{\max} = (1/\text{loss tangent})$, from 10^{-3} to 2×10^{-5} , sufficient for resolved extragalactic mm/submm spectroscopy, where intrinsic line widths are $\sim 10^{-4}$ to 10^{-3} . c) For KIDs, the interdigitated capacitors (IDC) currently used could be replaced by parallel-plate capacitors 40 times smaller in area, presenting a number of advantages. Currently, these IDCs can be an appreciable fraction of or even dominate the focal plane area. In KIDs for imaging at $350 \mu\text{m}$ (MAKO), it has been necessary to introduce the complexity of a microlens arrays to focus incoming light on the small active region of the



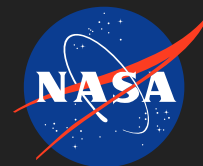
Project Image Shown is a radio frequency superconducting test circuit incorporating crystalline silicon as the dielectric layer for low-loss verification tests.

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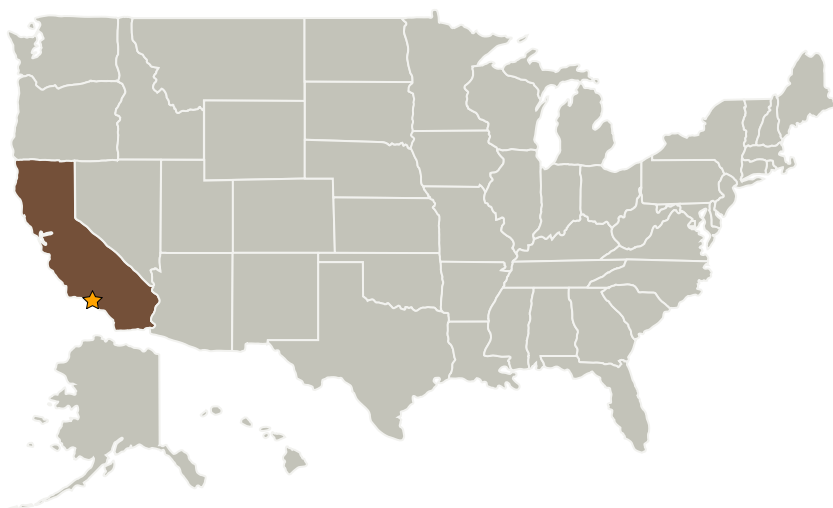
detectors. In KIDs for mm/submm spectroscopy (SuperSpec), the large IDCs render the array of KIDs so large that the spectrometer devices must be fabricated on individual chips and oriented normal to the focal plane rather than placing them in the focal plane, creating packaging challenges and degrading the scalability of the design. Furthermore, in KIDs for these purposes as well as coupled to phased-array antennas (e.g., the CSO MUSIC instrument), the IDCs act as unintended antennas that route incoming sub/mm power directly to the detector, circumventing the desired spatial filtering of the received light and increasing susceptibility to stray light. In the example of SuperSpec, the solution has been to require the detectors be hidden behind feedhorns, even though this again degrades scalability. IDCs also can yield inter-KID coupling that can confound the frequency-domain multiplexing that makes KIDs a compelling detector array technology.

Anticipated Benefits

This development would contribute to filling the Critical Technology Gaps identified in the 2014 PCOS and COR Program Annual Technology Reports, specifically the PCOS "Advanced millimeter-wave focal plane arrays for CMB polarimetry" gap and the COR "Large-format, low-noise far-infrared (FIR) direct detectors" and "Ultralow-noise FIR direct detectors" gaps.

This technology will demonstrate how fabrication with crystalline dielectrics can be used to build better superconducting detectors for other government agencies.

Primary U.S. Work Locations and Key Partners



Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Andrew D Beyer

Co-Investigators:

Charles M Bradford
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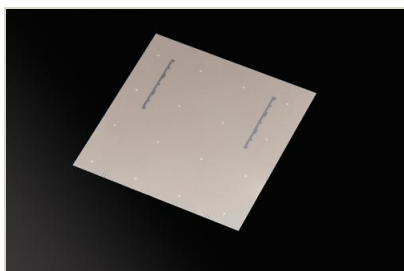


Organizations Performing Work	Role	Type	Location
★ Jet Propulsion Laboratory(JPL)	Lead Organization	NASA Center	Pasadena, California
California Institute of Technology(CalTech)	Supporting Organization	Academia	Pasadena, California

Primary U.S. Work Locations

California

Images



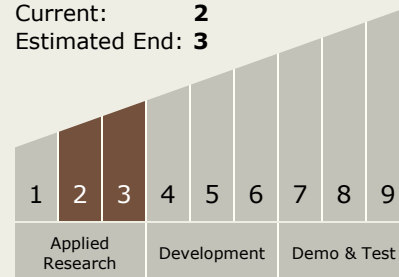
Low Loss Superconducting Microstrip Test Structure image

Project Image Shown is a radio frequency superconducting test circuit incorporating crystalline silicon as the dielectric layer for low-loss verification tests.

(<https://techport.nasa.gov/image/26092>)

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX08 Sensors and Instruments
 - └ TX08.1 Remote Sensing Instruments/Sensors
 - └ TX08.1.1 Detectors and Focal Planes